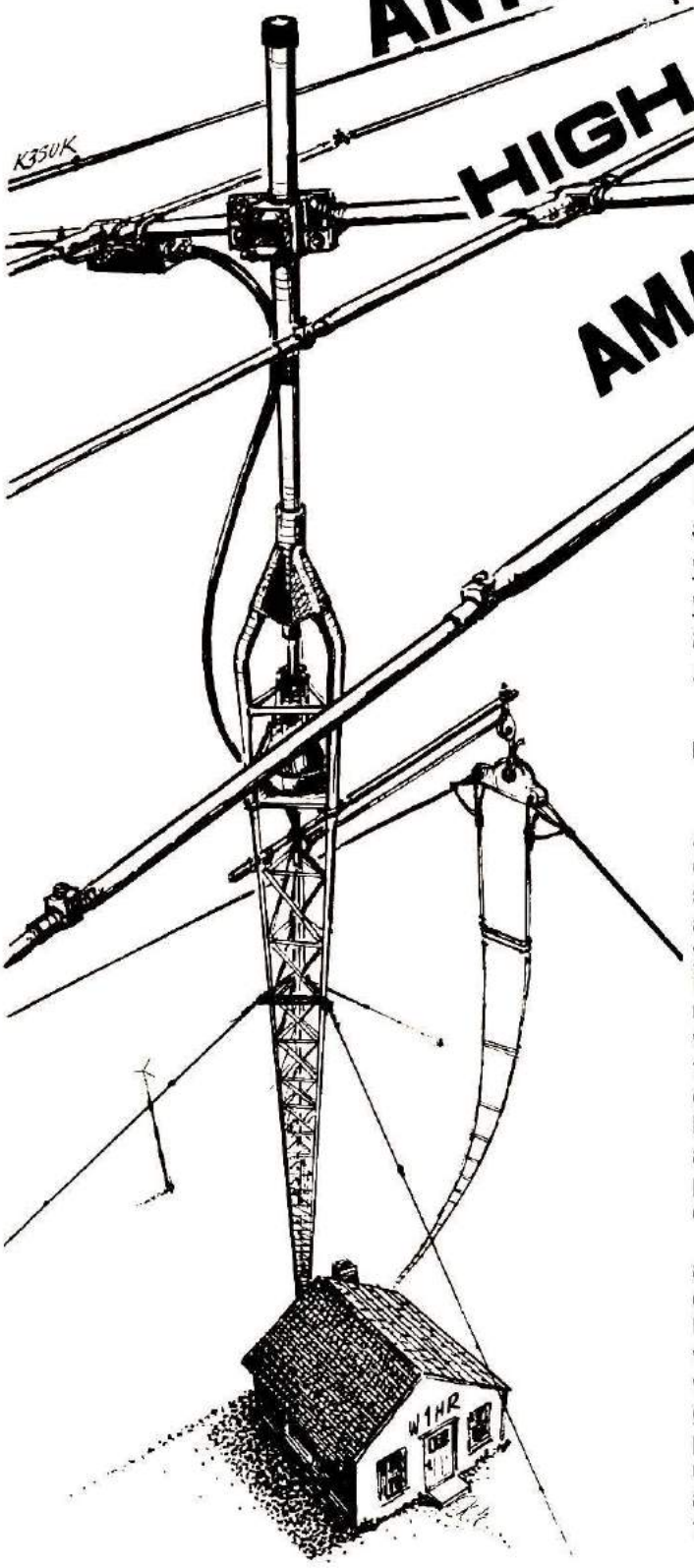
# ANTENNAS FOR THE HIGH FREQUENCY AMATEUR BANDS




*When you're putting together your amateur station, one of the most important decisions you'll have to make is what kind of antenna you're going to use. Here are some things to think about when you make that all-important decision*

**BY JAMES R. FISK, W1HR**

Antennas come in all shapes and sizes, and choosing the one that is best for your own station usually boils down to a compromise among how much space you have, the size of your budget, what Amateur bands you're interested in, and whether you want to work DX, run phone patches to the Antarctic, or ragchew with your ham friends across town. This is not to say that an antenna that works well for local contacts can't be used for DX — it can. However, the requirements for a good DX antenna are somewhat different than those used primarily for local contacts. In this respect choosing an antenna is a bit like buying a car.

If you regularly drive long distances, speed and comfort are important; if you commute, fuel economy may be the prime factor; if you have a large family you'll probably want a station wagon, and if handling and agility are what you want, you probably have a sportscar in your garage. Any car will get you from point A to point B, but the model you choose depends upon the kind of driving you do. So it is with antennas — the one you choose should be tailored to your own operating habits.

Obviously you want the best antenna you can

put up, but before you make that all-important choice, you have to know something about the many types of antennas which are available and why some are more popular and work better than others. In this article we'll describe some of the many types of antennas used by amateurs, give you some hints for putting them up, and tell you how to get the most for your money.

Fortunately, an acceptable antenna is often easier to put up than it is to describe, but we have to start somewhere, and a good starting point is the word antenna itself. The origin of the term is obscure but stems from the Latin word for "sail yard." If that calls to mind pictures of tall ships and lofty sails, you're getting the right impression because your antenna should be as high and as large as possible, within reason. Usually it's not possible to install an ideal antenna, so you have to put up the best possible compromise — and if you look around, you'll find that most hams have compromise antenna installations for one very practical reason: Cost.

The first requirement for a high-frequency antenna is that it must be made from material which is a good conductor of electricity. Wet string, even if it's soaked in salt water, just won't do. There are a number of good electrical conductors with silver about the best, followed by copper, gold, chromium, aluminum, magnesium, beryllium, sodium, molybdenum, rhodium, tungsten, and zinc, in order of increasing resistance. Ruling out the precious metals because they're too expensive, and some of the others because they're difficult to work with (too soft or too brittle), leaves copper, aluminum, and zinc. Phosphor-bronze, a copper-based alloy, is also a good choice.

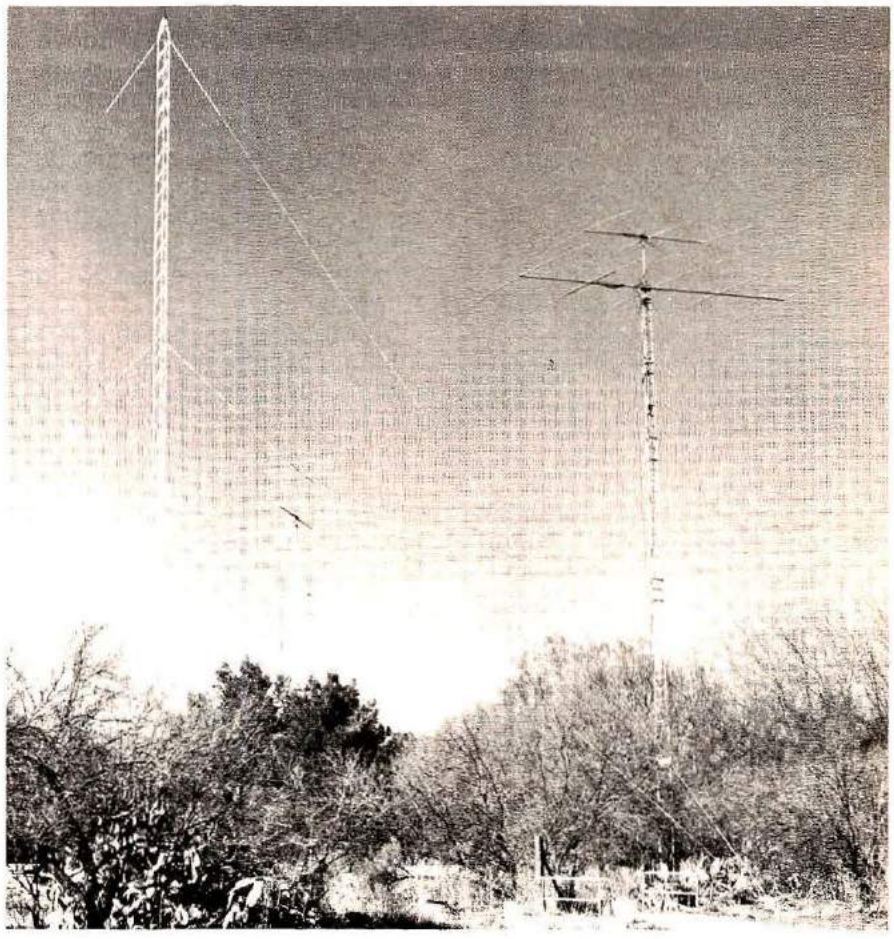
Copper is perhaps the closest to an ideal material from the standpoints of availability, cost, strength, weight, and ease of fabrication including soldering. Aluminum is next best and, for some types of antennas where weight is a major consideration, may be the better selection.

At radio frequencies the current flow tends to be concentrated near the surface of the conductor; this is called "skin effect" and is due to internal effects. Since rf current flow is confined to an area near the surface, the rf resistance is many times the dc resistance and increases at higher frequencies. On 160 meters, for example, most of the rf current flow in a copper wire is within two-thousandths of an inch of the surface (2 mils or 50 microns). This decreases to 0.5 mil (12 microns) at 28 MHz.

Because of skin effect, a length of copper tubing has exactly the same rf resistance as a solid copper conductor with the same diameter. It also means you don't have to use solid-copper conductors at high frequencies. *Copperweld** antenna wire, which consists of a steel core with a thin copper coating, is often used for antennas because it is much stronger and stretches less than solid copper wire; above 1 MHz its rf resistance is the same as solid copper wire of the same size.

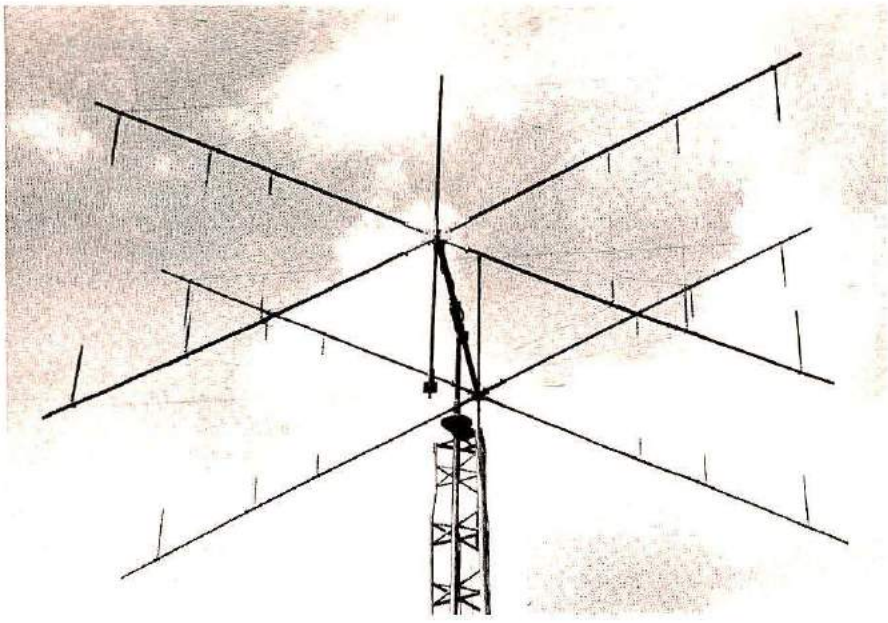
### Receiving antennas

If you're only interested in listening, your antenna can be a random length of wire, perhaps 20 to 25 feet (6-8 meters) long, attached to a tree, run under the eaves of your house, or even hung out



The antenna farm at W7IR near Phoenix, Arizona, includes rotating Yagi beams for 20 and 15 meters, right; beams for 40 and 10 meters, center; and a 91-foot (28m) vertical for 80 and 160 meters, left.

**Copperweld* is the registered trademark of the Copperweld Corporation of Glassport, Pennsylvania.



This cubical quad built by W1HXU provides high-gain performance on the amateur 10, 15, and 20 meter bands.

the window if you live on the upper floor of an apartment house. Modern receivers are very sensitive, so you can get quite good results with a very simple antenna. If you live in a wooden building, you can even install an antenna in the attic or other convenient place — steel-reinforced concrete is a very effective rf shield, so an outdoor antenna is a must if you live in a modern high-rise. However, there are simple solutions to this problem, as you shall see.

Fortunate indeed is the apartment dweller whose landlord will say, "Sure, go ahead and put your antenna on the roof if you want to." These enlightened souls are few and far between, so if your landlord is one of these, take good care of him.

**Wire or tubing?**

The choice of wire or tubing for your antenna depends largely upon whether your antenna will be vertical or horizontal, and that, in turn, depends upon the available space and what kind of operating you intend to do. On the lower frequency amateur bands, 80 and 40 meters, the physical size of the antenna almost always dictates that it be made of wire and suspended horizontally above the ground. Vertical antennas made from aluminum tubing can also be used to good advantage on these bands, but for maximum performance they require a good ground system (not a ground rod) that is expensive and time consuming to install.

For the higher frequency amateur bands, 20, 15, and 10 meters, the antenna may be a horizontal length of wire, a vertical made from tubing, or two or more sections of aluminum tubing arranged in an array of elements or beam. Without going into a lot of detail at this point, verticals for 10, 15, and 20 meters have one outstanding advantage over other types — they can be put up in very limited space and don't require trees, masts, or chimneys to support the ends. The ground-system requirements at these frequencies are somewhat easier to meet than at the lower frequencies, so a vertical is an excellent choice and often represents the best compromise in many space-limited situations. For the apartment dweller a vertical may provide the *only* antenna solution; they have been attached to porch railings, window sills, flag poles, and even eaves troughs.

**Antenna resonance**

Although it may not look like it, every antenna is really a complex electronic circuit with resistance, capacitance, and inductance. This is further complicated by the fact that the nature of these components varies with frequency, height above ground, and how close the antenna is to other objects. In fact, there are some antennas which defy analysis, even with modern, high-speed, digital computers. This is one of the reasons why few amateurs design their own antennas — there are any number of proven designs available which are easy to duplicate and give good results.

There are certain frequencies where the effects of inductance and capacitance cancel out, so at this point the antenna is said to be resonant. Below resonance the antenna looks like a capacitance, and above resonance it looks like an inductance. This is important to remember because it can be used to advantage if your space is limited and you have to use an antenna that is "too short."

The shortest antenna that is naturally resonant at a given frequency is one just long enough to permit the rf current to travel from one end to the other and back again during the time of one rf cycle. Radio waves travel through space at the speed of light, approximately 300,000,000 meters per second, so the distance a wave travels is one cycle is equal to this speed divided by the frequency in Hz. This is called the wavelength. At 4 MHz (4-million Hz), for example, the wavelength is 75 meters. Since the wave travels the length of the antenna *twice*

— from one end to the other and back again — an antenna *one-half* wavelength long will allow the rf current to travel one complete wavelength during one rf cycle. Therefore, the shortest resonant antenna is one that is one-half wavelength long.

If you were to use the speed of light as the basis for figuring out the length of your wire antenna, and then installed insulators at each end and suspended it between two masts, you'd find that it would resonate at a slightly lower frequency than you wanted. This is because of the so-called *end effect* which is caused by the small amount of capacitance introduced by the supporting insulators. End effect varies with frequency and with different installations, but up to about 30 MHz experience has shown that the length of a wire antenna is about 5 percent less than the length of a half-wavelength in space. As an average, the following formula can be used to find the physical length of horizontal wire antenna

$$L = \frac{468}{f_{MHz}} \text{ feet}$$

$$L = \frac{142}{f_{MHz}} \text{ meters}$$

where $L$ is the length and $f$ is the frequency in MHz. For example, if you want to operate at 3.725 MHz in the 80-meter Novice band, the length of a half-wavelength antenna is

$$L = \frac{468}{3.725} = 125.64 \text{ feet}$$

or 125 feet, 7-5/8 inches

$$L = \frac{142}{3.725} = 38.1 \text{ meters}$$

**Table 1** gives the dimensions for half-wavelength wire antennas for various frequencies in each of the six high-frequency amateur bands from 160 through 10 meters.

Although an antenna is naturally resonant at only one frequency within an amateur band, it can be used quite successfully both above and below resonance. This is because the matching network in your transmitter compensates for non-resonance, within limits. In fact, if you cut your antenna for the center frequency of an amateur band, in most cases it will operate with good efficiency from one end of the band to the other. The 80-meter band is an exception; this is because the output loading circuits built into most transmitters don't have enough tuning range to compensate for the high reactance at the band edges when the antenna is cut for 3.75 MHz. The best bet here is to use an antenna tuner. Some other alternatives will be discussed later.

**Table 1.** Length of half-wavelength wire antennas for various frequencies in the high-frequency bands.

| Band | Frequency (MHz) | Use | Half Wavelength (feet) | Half Wavelength (meters) |
|---|---|---|---|---|
| 160 | 1.825 | General | 256.4 | 77.81 |
| 160 | 1.875 | General | 249.6 | 75.73 |
| 80 | 3.725 | Novice | 125.6 | 38.12 |
| 80 | 3.750 | General | 124.8 | 37.87 |
| 80 | 3.600 | CW | 130.0 | 39.44 |
| 75 | 3.800 | Phone | 123.2 | 37.37 |
| 40 | 7.175 | Novice | 65.2 | 19.79 |
| 40 | 7.150 | General | 65.5 | 19.86 |
| 40 | 7.100 | CW | 65.9 | 20.00 |
| 40 | 7.250 | Phone | 64.6 | 19.59 |
| 20 | 14.150 | General | 33.1 | 10.04 |
| 20 | 14.050 | CW | 33.3 | 10.11 |
| 20 | 14.275 | Phone | 32.8 | 9.95 |
| 15 | 21.175 | Novice | 22.1 | 6.71 |
| 15 | 21.225 | General | 22.0 | 6.69 |
| 15 | 21.100 | CW | 22.2 | 6.73 |
| 15 | 21.350 | Phone | 21.9 | 6.65 |
| 10 | 28.150 | Novice | 16.6 | 5.04 |
| 10 | 28.050 | CW | 16.7 | 5.06 |
| 10 | 28.550 | Phone | 16.4 | 4.97 |
| 10 | 29.475 | Oscar | 15.9 | 4.82 |

### Radio propagation

It may not be immediately apparent, but radio propagation has a good deal to do with antenna selection and design. You don't have to completely understand *all* the ins and outs of propagation to select an antenna, but a basic understanding will help

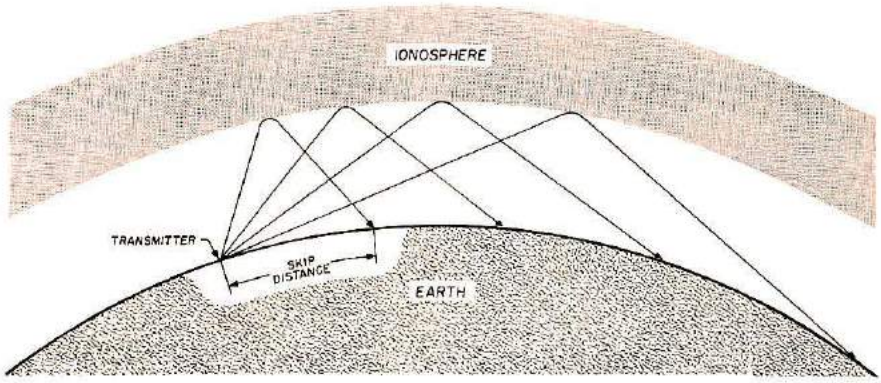



**Fig. 1.** Radio propagation by sky wave, rf radiation which is reflected by the ionosphere. The skip distance is determined by both the angle at which the rf leaves your antenna, and the height of the ionosphere, which depends upon time of day, season, and latitude among other things. During periods of low sunspot activity, as now, the ionosphere is most effective on 40 and 20 meters. During the next sunspot high in 1981, daily round-the-world propagation on 10 and 15 meters will be common, and there may even be occasional "openings" on 50 MHz!

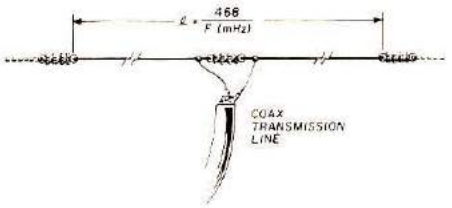



**Fig. 2.** Dipole or doublet antenna provides a good match to 50- or 75-ohm coaxial transmission lines. Proper length depends on the desired operating frequency as shown in **Table 1**.

you choose an antenna that will do the job you want it to.

Basically, radio waves propagate in three different ways: line of sight, ground wave, and sky wave. For line-of-sight propagation your antenna has to "see" the antenna of the station you want to work. Since high-frequency radio waves are slightly bent by the atmosphere, radio line-of-sight is about 20 per cent greater than the distance you can see on a clear day. If you live in the midwest where the land is flat for miles around, and your antenna is 100 feet (30m) high, maximum radio line-of-sight is about 15 miles (24km).

The ground wave is simply that portion of the radiated energy which moves along the surface of the ground; a certain amount of rf from *all* antennas is radiated in this fashion. On the a-m broadcast band the ground wave accounts for propagation up to 100 miles (160km) or more during the daytime, but range falls off quickly with increasing frequency — on 160 and 80 meters it provides reliable communications only to 50 miles (80km) or so. On the higher frequency bands the energy in the ground wave is quickly dissipated in ground losses so it's useful only for close-in radio communications.

Dentron 80-10AT antenna tuner is designed to load a random length of wire on 80 through 10 meters. It's ideal for portable operation or for apartment dwellers who have limited space. Maximum power rating is 500 watts PEP.

Almost all high-frequency radio propagation is by way of the sky wave, rf energy which is reflected off the ionosphere back to earth as shown in **Fig. 1**. The height of the ionosphere varies with the time of day, season, and latitude among other things, and may be anywhere from 125 to 250 miles (200-400km) above the earth. As can be seen from **Fig. 1**, maximum skip distance occurs when the rf from your antenna is concentrated within a few degrees of the horizon. At higher radiation angles the skip distance is much shorter. This is the reason why most serious DX operators choose antennas which have very low angles of radiation such as multi-element Yagi beams or cubical quads.

### Dipole antennas

One of the simplest, most effective antennas for amateur use is the dipole or doublet antenna shown in **Fig. 2**. This is the same type of antenna used by Heinrich Hertz in his first experiments with radio waves back in 1887, so it is sometimes referred to as a *Hertz* antenna. Amateurs usually use dipole antennas which are one-half wavelength long because they're easy to put up and provide a good match to 50- and 75-ohm transmission lines. Longer (or shorter) dipoles can also be used, but if the length is considerably different than one-half wavelength, the antenna will not provide a good match to a coaxial transmission line so an external antenna matching unit will be required.

As I mentioned earlier, the height above ground and the nearness of other objects has an effect on the way the antenna behaves. These things also affect the feedpoint inpedance of the antenna. Out in free space the theoretical input impedance of a half-wave dipole is 72 ohms, but when installed over ground the impedance varies from zero (at ground level) to nearly 100 ohms (about 3/8 wavelength above ground) as shown in **Fig. 3**. Note that this assumes a *perfect* ground, not a lossy, real-life ground.

The ground under your antenna may be very good (if you live in a salt marsh) or very poor (if you live in the desert) but it will never be perfect. Nevertheless, this graph should give you an idea of the range of impedance values provided by a half-wavelength dipole. Many antenna books suggest that the dipole be installed 1/2 wavelength above ground — this isn't always practical, but if you can manage it the feedpoint impedance should be somewhere around 72 ohms.

### Radiation resistance

The rf energy supplied to your antenna through the transmission line is dissipated in the form of radio waves and in heat losses in the antenna conductor and the insulators. Since the antenna is made from a good conductor of electricity, heat losses due to

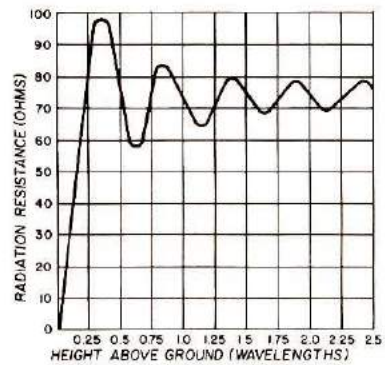



**Fig. 3.** Radiation resistance of a horizontal half-wavelength dipole varies with height above a perfectly conducting ground. The earth under your antenna is not a perfect conductor, but this graph will give you an idea of the range of feedpoint impedance values to expect.

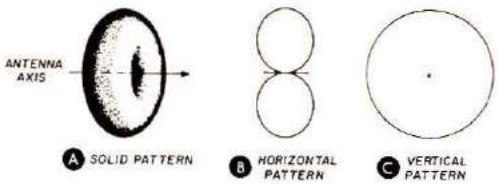



**Fig. 4.** Radiation pattern of a half-wavelength dipole in free space looks a bit like a doughnut as in **A**. Since the radiation patterns of most antennas aren't as simple as this, it's difficult to present a three-dimensional view, and both horizontal and vertical patterns are used. The horizontal radiation pattern of the free-space dipole, as seen from the top, looks like a figure eight, **B**; the vertical pattern as seen from the end of the antenna looks like a circle, **C**.

the ohmic resistance of the wire are very low. The radiated energy is the useful part and since it, too, is dissipated, — so far as the antenna is concerned the radiated energy *looks* like it was dissipated in a resistance. This fictional resistance is called radiation resistance.

In an ordinary half-wavelength dipole made from number 14 (1.6mm) copper wire, the loss resistance is less than 1 ohm and radiation resistance makes up the rest. The 72-ohm feedpoint impedance of a half-wavelength dipole, for example, consists of about 71 ohms of radiation resistance and 1 ohm of loss resistance. Any energy which is dissipated in the loss resistance is not radiated, so it's important to keep the loss resistance as low as possible. For full-size antennas this is forced to use a "short" antenna because of space limitations, you'll find that the feedpoint impedance may be 10 ohms or less; the ohmic resistance will still be on the order of 1 ohm so it represents about 10 per cent loss. In some mobile antennas for 80 and 160 meters the loss resistance may even be greater than the radiation resistance. This dramatically reduces the efficiency of the antenna. Nevertheless, small antennas can provide surprisingly good results.

MFJ antenna tuner can be used to tune your transmitter into a random length of wire on any amateur band between 160 and 10 meters. It's rated at 200 watts, maximum.

### Radiation patterns

All antennas have a distinctive radiation pattern which shows how well the antenna radiates energy in any given direction. Most simple antennas radiate energy in most all directions, but multi-element arrays concentrate the energy in one direction like a beam of light. The radiation pattern is three dimensional so it's difficult to illustrate it properly on the printed page. Therefore, antenna radiation patterns are usually presented in two views: Horizontal (as seen from a point directly above the antenna) and vertical (a side view from ground level).

A half-wavelength dipole in free space, for example, has a radiation pattern that looks something like a doughnut as shown in **Fig. 4A**. As seen from the top, the horizontal radiation pattern takes the form of a figure 8 (**Fig. 4B**). The vertical radiation pattern, as seen from the side, is a circle as in **Fig. 4C**. Note that this is the radiation pattern of a half-wave dipole out in free space where it's not affected by reflections from the ground.

The antennas that you and I use are not out in free space, so they are subject to the influences of the earth which intercepts the radio waves travelling to and from the antenna, and distorts or absorbs them. If the earth under your antenna is a good conductor (which it usually is not), the radio waves near the antenna and underneath it are reflected by the earth and bounce back into space, sometimes reinforcing each other and sometimes cancelling one another, or a little of both. The various combinations of reflection, interference, and absorption change the radiation pattern of the dipole. The overall effect depends upon the height above ground as shown in **Fig. 5**.

The Universal Radio *Tripole* multiband antenna is designed for use on 80 through 10 meters, and provides a good match to 50-ohm coaxial transmission lines. An optional matching network is available which permits operation on 160 meters as well.

Experimenters have tried all different heights for their half-wavelength dipoles, and discovered long ago that the

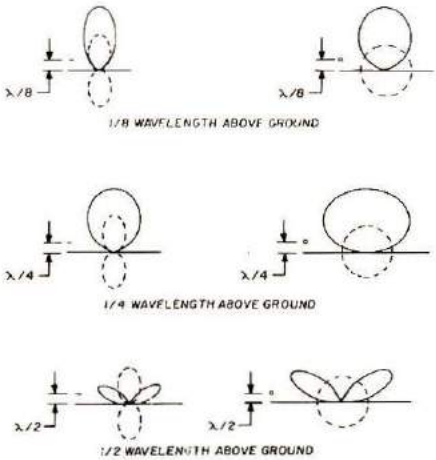



**Fig. 5.** Horizontal and vertical radiation patterns of a half-wavelength dipole 1/8, 1/4, and 1/2 wavelength above ground. Note that maximum power is concentrated at low vertical angles when the antenna is 1/2 wavelength high — at other heights most of the energy is concentrated in a vertical lobe; this is fine for medium-range communications but not best for long-range DX work.

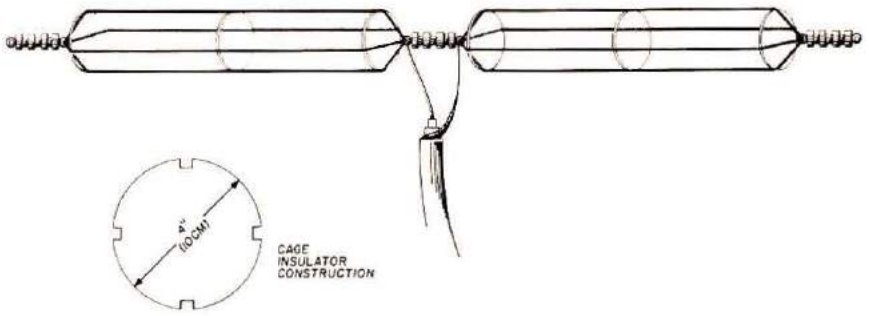



**Fig. 6.** Operating bandwidth of an 80-meter dipole is limited because the output circuits of modern transmitters aren't designed to cope with the off-resonance effects; the antenna is just as effective at a band edge as it is in the center, but your transmitter is incapable of loading maximum rf power input into it. This can be solved by using a "thick" dipole which is simulated by a cage of wires as shown here.

best height above ground was 1/2 wavelength. As can be seen in **Fig. 5**, when the dipole is 1/2 wavelength above ground, the energy in the vertical pattern is concentrated at an angle of about 30 degrees above the horizon. At 1/8 and 1/4 wavelength above ground most of the rf energy from the dipole is radiated straight upward toward the sky. This is fine for short- and medium-range communications, but not very good for DX work. At greater heights above ground the radiation is again concentrated in a vertical lobe, so a height of 1/2 wavelength is about optimum for good DX operation.

It's not usually possible to place your dipole a half wavelength above ground on 80 and 160 meters, so do the best you can. With antennas, as in life, everything turns out to be a compromise of one kind or another, so put your 80- and 160-meter antenna as far above ground as you can and don't worry about it. On the higher frequency bands a half wavelength becomes smaller and smaller, so at 40 meters it is only 65 feet (20 meters) or so; not easy, but not impossible, either. On 20 meters it's about 34 feet (10 meters), and so on down the scale.

### Broadband dipoles

If you want to operate on the 80-meter band and cut your dipole to resonate in the center of the band at 3.75 MHz, if you use a coaxial transmission line you'll probably find that your transmitter won't load properly as you get near the band edges. The antenna itself is just as effective at the band edges as it is at resonance if you can get rf power into it, but the output matching network in your transmitter isn't able to cope with the off-resonance effects caused by operation more than about 2 or 3 per cent away from resonance.

This is not a problem on 40, 20, and 15 meters because the width of these bands is a small percentage of the center frequency. If you use a coaxial-fed dipole on 80 meters, however, the maximum bandwidth you can expect to cover before running into transmitter loading problems is about 200 kHz. Remember that this is not a problem with the antenna — it's a limitation of your transmitter. Fortunately, there are some simple solutions to this problem that will allow you to operate anywhere on 80 meters with a single antenna.

One of the easiest ways to solve the bandwidth problem on 80 meters is to increase the diameter of the dipole. This is because the off-resonance effects are less drastic if you use a "thick" dipole, so the operating bandwidth is increased. Thick dipoles made from aluminum tubing are often used on the vhf bands, but stringing up a 125-foot (38-meter) length of aluminum pipe for 80 meters obviously isn't too practical. However, you can simulate the same thing by using the arrangement shown in **Fig. 6** which is called a cage dipole. This type of construction provides a pretty good match to coaxial cable over the entire 80-meter band.

Another way to simulate a thick dipole is to use the fan arrangement in **Fig. 7**. This type of construction was originally conceived back in the 1930s for wideband TV reception and you can still see it today in many uhf-television "bow-tie" antennas. This antenna will also provide a good match to a coaxial feedline over the entire 80-meter band.

Still another approach to satisfactory operation from one end of the 80-meter band to the other is shown in **Fig. 8** — use open-wire feeders and an antenna matching unit or antenna tuner. You can also use coaxial feedline and an antenna tuner to provide a good match to your transmitter, but losses are considerably lower if you use open-wire feedline. Although this type of antenna requires the use of an additional piece of equipment

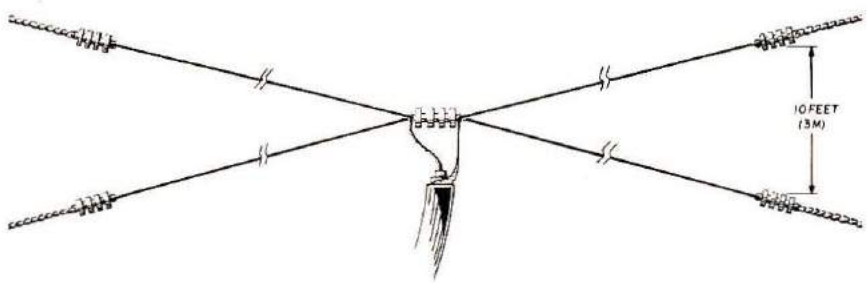



**Fig. 7.** The fan dipole is another way to increase your operating bandwidth on 80 meters. This arrangement is somewhat easier to build than the cage dipole shown in **Fig. 6**.

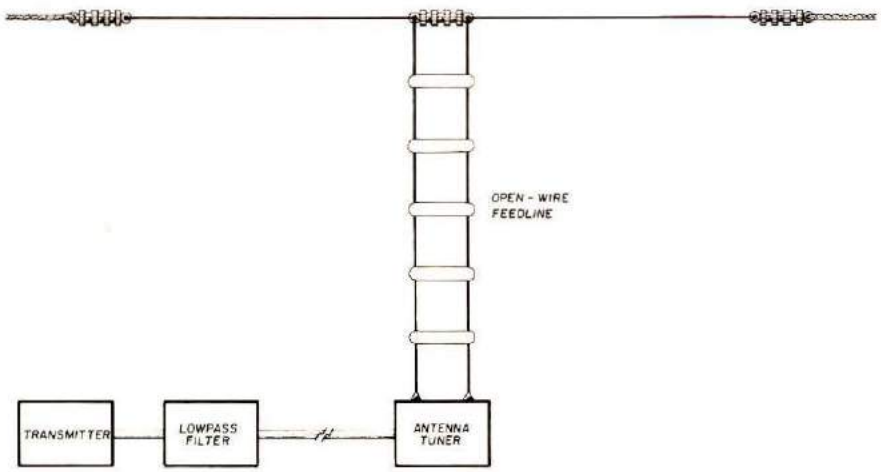



**Fig. 8.** This antenna system can be used on any of the high-frequency amateur bands with good results. It does require the use of an antenna tuner, but if you have space for only one antenna, this is an excellent choice. The dipole should be 1/2-wavelength long on the lowest amateur band you intend to use (about 125 feet or 38 meters on the 3.5-MHz band).

— the antenna tuner — it has the added advantage that it can be used on *any* of the amateur bands.

If your space is limited so you can only put up one antenna, this is an excellent choice. You do have to readjust the antenna tuner for each band, but that doesn't present much of a problem after you have tuned it correctly the first time; just write down each of the control settings and keep the list nearby — in the future all you have to do is return the antenna tuner to those dial settings, which only takes a few seconds.

The half-wavelength folded dipole shown in **Fig. 9** is yet another way to increase your usable operating bandwidth on 80 meters over that of a single-wire dipole. The feedpoint impedance of the folded dipole is about 300 ohms, so if you want to use a 50-ohm transmission line, you"ll have to install a 4:1 matching transformer which will transform the 300-ohm feedpoint impedance to the 50-ohm impedance of your cable. Years ago, when amateurs regularly used balanced open-wire feedlines or TV twinlead, the folded dipole was very popular, but today it is seldom seen. In most cases, the fan dipole or cage dipole are a better choice if you want to operate from one of the 80-meter bands to the other.

### Other dipoles

One of the big disadvantages of the horizontal dipole is that it requires a high mast or tree at each end. If you're fortunate enough to have some high trees in your backyard which are the right distance apart, you're all set, but most amateurs aren't so lucky. One very popular solution to this problem is to elevate the center of the dipole and allow the two halves to slope down toward the ground as shown in **Fig. 10**. This is called an inverted-V. In addition to needing only one high supporting mast, it requires much less horizontal space. Some amateurs have even reported that the inverted-V is more effective than the horizontal dipole on 40 and 80 meters, particularly at heights above ground of 75 feet (23 meters) or less.

Sloping the halves of the dipole down toward ground tends to lower the resonant frequency of the antenna; it also decreases the feedpoint impedance and bandwidth. Therefore, the length of the inverted-V must be shortened somewhat to resonate at the same frequency as a horizontal dipole. Since both resonance and feedpoint impedance are a function of the apex angle (which should not be less than 90 degrees), there's no fixed formula for figuring out the correct length. The best bet is to cut the antenna to the length shown in **Table 1** and equally shorten the length of each half until the antenna provides a good match to your 50-ohm coax at the desired operating frequency. As with horizontal dipole antennas, bandwidth can be increased by using a cage of wires similar to that in **Fig. 6**.

The Millen *Transmatch* is designed to match antennas on the 80, 40, 20, 15, and 10 meter bands. The unit has a built-in swr meter and is rated at 2000 watts.

Still another variation on the dipole theme is the "sloper" shown in **Fig. 11**. This antenna

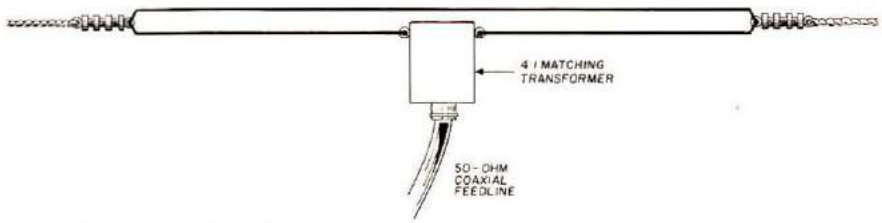



**Fig. 9.** The folded dipole has somewhat greater bandwidth than a single-wire dipole, but the feedpoint impedance is 300 ohms so you have to install a 4:1 matching transformer if you use 50-ohm coaxial feedline. In general, the cage dipole (**Fig. 6**) or the fan dipole (**Fig. 7**) are a better choice for complete band coverage on 80-meters.

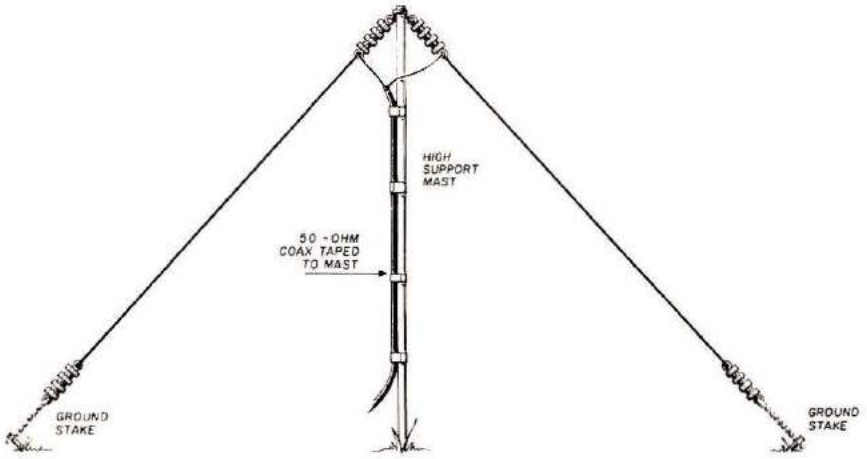
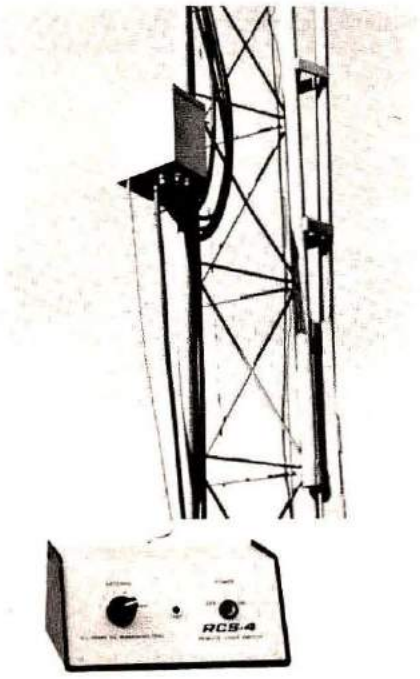



**Fig. 10.** The popular inverted-V is simply a half-wavelength dipole with the ends sloping down toward the ground. This antenna requires somewhat less space than a horizontal dipole, and needs only one high mast. Resonant frequency depends upon the apex angle and height above ground, so the length of the antenna must be "pruned" to the correct length as discussed in the text.

requires only one high support mast and is very popular for DX work because maximum radiation is at low vertical angles. Some DXers have even installed four sloping dipoles on the same mast, 90 degrees apart, so they can direct their transmissions to different areas of the globe simply by switching the coaxial feedline from one sloper to another. This can be done manually, or with an electrically-driven coaxial switch which is mounted on the support mast and controlled from the shack.




The R. L. Drake RCS-4 remote coaxial switch is ideal for switching the various legs of a sloper antenna system. It can also be used for switching your transmission line between other antennas which are located on the same tower.

The length of a dipole does not have to be limited to one-half wavelength — lengths much longer (or shorter) can be used, but they don't present good matches to 50- or 75-ohm transmission lines. An exception here is a dipole which is an *odd* multiple of 1/2-wavelength long, such as 3/2 (1-1/2) or 5/2 (2-1/2) wavelengths; the behavior of these dipoles is very similar to that of half-wave antennas and they provide a good match to coaxial transmission lines. This is important because a 1/2-wavelength dipole for 40 meters is 3/2-wavelengths long on 15 — this means that the same antenna can be used on both bands. None of the other high-frequency amateur bands have this relationship.

Dipoles which are an *even* multiple of 1/2-wavelengths long (such as 1, 2, 3, or 4 wavelengths) present a very high feedpoint impedance, so it's not a good idea to use them with coaxial transmission lines. A practical example is a 1/2-wavelength 3.5-MHz dipole which is 1 wavelength long on 7 MHz, 2 wavelengths long on 14 MHz, and 6 wavelengths long on 21 MHz. If you use open-wire feeders and an antenna matching unit (see **Fig. 8**), however, the 80-meter antenna is a very effective radiator on *all* high-frequency bands, even on 160 where it is only 1/4-wave long! Dipoles which are longer than 1/2 wavelength have a slight amount of gain over a half-wave dipole at the same height above ground, but gain is less than 3 dB for dipoles shorter than four wavelengths.

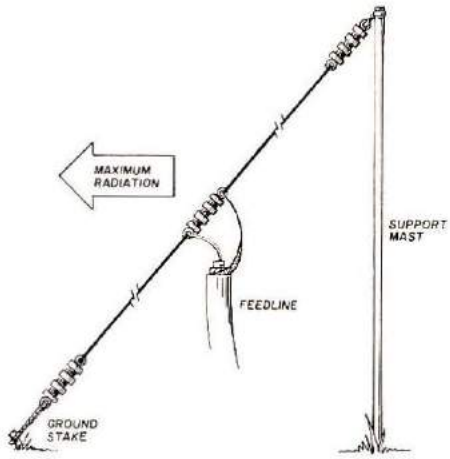



**Fig. 11.** The "sloper" antenna is very popular for DX work on the lower frequencies because the rf is concentrated at low vertical radiation angles. Length of the antenna is one-half wavelength (use dimensions given in **Table 1**).

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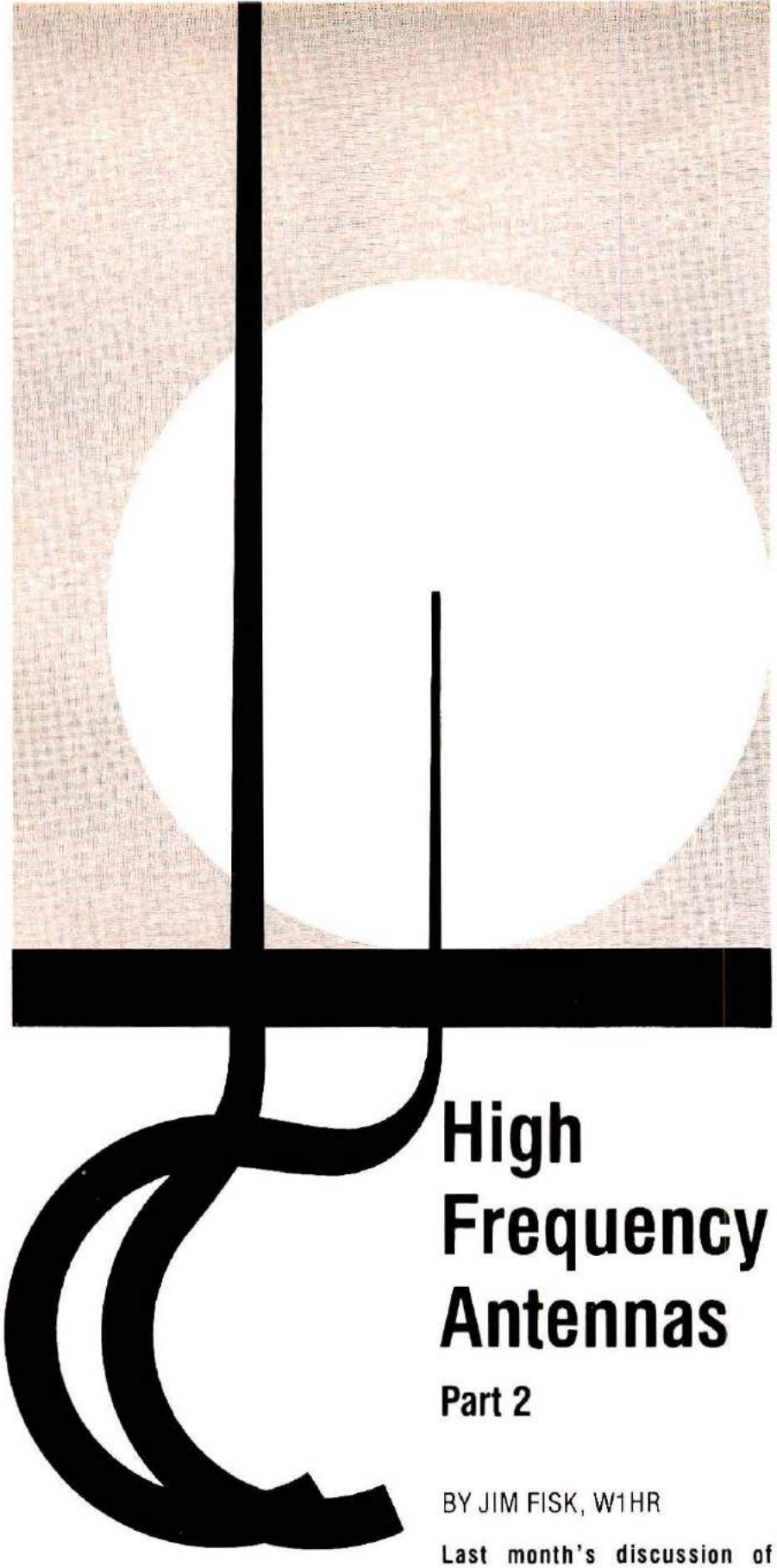


# High Frequency Antennas

## Part 2

BY JIM FISK, W1HR

**Last month's discussion of simple antennas continues — with details on verticals, multi-element arrays, and high-gain beams and cubical quads.**

### Vertical antennas

Although half-wave dipoles are usually thought of as horizontal antennas, they can also be installed vertically. However, most vertical antennas for the high-frequency amateur bands are one-quarter wavelength high and operated against a good ground system as shown in **Fig. 12**. This is called a *Marconi* antenna. The other half of the vertical is the image so it looks like you're getting a half-wavelength antenna for the price of a quarter-wave element. Unfortunately, for maximum performance you have to provide a very good system of ground radials around the base of the vertical radiator, and this may cost you more than the radiator itself!

Recall that the feedpoint impedance of an antenna consists of both radiation resistance and unwanted loss resistance. The ohmic losses of the vertical radiator are quite low, but half the antenna is provided by the image — unless you have an extensive ground system the loss resistance of the image will be very high and efficiency will be low.

Broadcast stations commonly use 120 radials, each a half wavelength long, splayed apart like bicycle spokes at 3-degree intervals. Few amateurs go to the time and expense of installing 120 radials, but if you're serious about the performance of your vertical on 80 or 40 meters you should probably use no less than 40 radial wires. On 14, 21, and 28 MHz you can use less than this with good results.

If you're now using a vertical and your ground system consists of a single ground rod, you'll see a significant increase in performance if you install as few as four radials, spaced 90 degrees around the base of the antenna. Later on you can add more radials as you have the time and money. Most amateurs bury their radials several inches below the

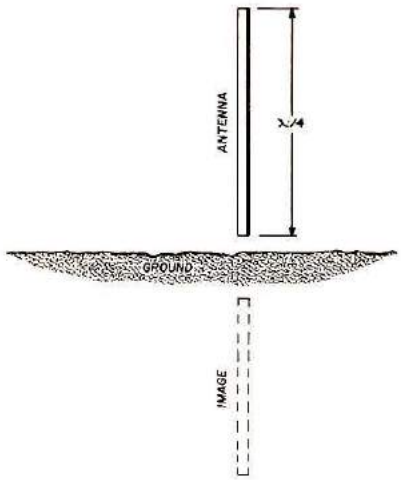



**Fig. 12.** The basic vertical antenna consists of a quarter-wave vertical radiator; the other half of the resonant system is provided by the image antenna in the ground. For maximum efficiency a vertical antenna requires a good ground system (not just a ground rod) which may cost more than the vertical radiator.

surface of the ground, but this isn't necessary if there's no chance someone will trip over them. If you have children, or live in a neighborhood where people are likely to be walking through your yard, you have no choice but to bury them. If you're moving into a new house and the lawn hasn't been seeded, you can lay the radials out on the surface of the ground and rake loose soil over them. When the lawn begins to grow, the roots of the grass will lock the wires in place just below the surface.

Copper wire is the best choice for a radial system, but unless you own stock in a copper mine, you'll have to use aluminum or galvanized steel wire. Both are good performers, and since both are used for electric fencing, you can buy quarter-mile (1320-feet or 402-meter) reels from Sears or Wards for a very reasonable price. Choose the largest diameter that is available, preferably larger than no. 14 (1.6mm).

Each of the radials in the ground system should be a minimum of 0.4 wavelength long. If your lot size won't accommodate this length, you can use shorter radials if the outer end of each one is terminated with a driven ground rod.

A vertical antenna radiates equally well in all directions, and this may be an advantage, but it also receives equally well from all directions which may be a disadvantage — particularly if you're trying to work a weak station in one direction and a strong interfering signal is coming in from the opposite direction. Vertical antennas are also more susceptible to man-made noise and lightning static because these sources of noise are vertically polarized. Nevertheless, if you're serious about working over long distances on 80 and 40 meters, the quarter-wave vertical is an excellent choice if you can manage the height.

A quarter-wave vertical on 80-meters is about 65 feet (20 meters) high, which may be difficult to manage, but heights much less than a full quarter-wavelength provide very good results if properly designed. Since an electrically "short" antenna is capacitive, as previously noted, inductance must be provided externally to tune the antenna to the desired operating frequency. Either base loading (an inductor at the base of the antenna) or center loading (a coil at the center of the antenna) may be used, but for a number of reasons, center loading provides much more efficient operation. The loading coil should have very low loss for best results. This is the

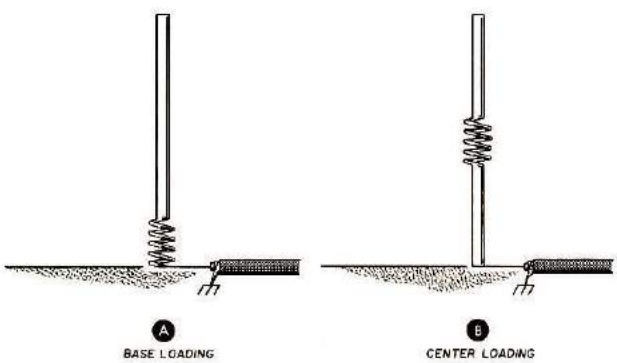



**Fig. 13.** When an antenna is too "short" for the desired operating frequency, it looks capacitive. Therefore, it can be resonated by adding inductance. Both base loading, **A**, and center loading, **B**, are commonly used, but center loading provides higher efficiency.

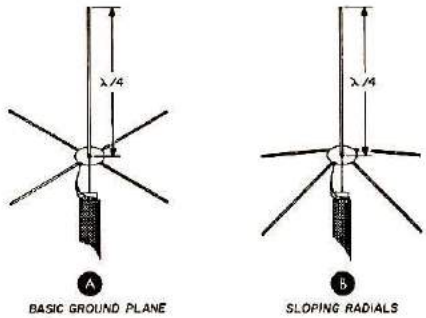



**Fig. 14.** The ground-plane antenna is popular on the higher frequency amateur bands. The antenna is usually mounted on a high mast well away from nearby objects; the ground is simulated by the four quarter-wavelength radials arranged around the base of the vertical radiator. When the radials are horizontal as shown in **A** the feedpoint impedance is about 37 ohms; if the radials are allowed to droop as in **B** the feedpoint impedance is close to 50 ohms and provides a good match to coaxial transmission lines.

type of antenna which is often used for mobile operation on 80 and 40 meters.

### Ground-plane antennas

One type of antenna which is very popular on 20 meters and the higher-frequency amateur bands is the ground-plane antenna shown in **Fig. 14**. This antenna is usually installed well above the ground away from trees and nearby objects which might distort the radiation pattern. In this antenna the ground system consists of four radials around the base of the antenna. Ground-plane antennas are usually built from aluminum tubing and are often used to provide omnidirectional (all directions) coverage on vhf. If the radials are allowed to droop at an angle of about 30

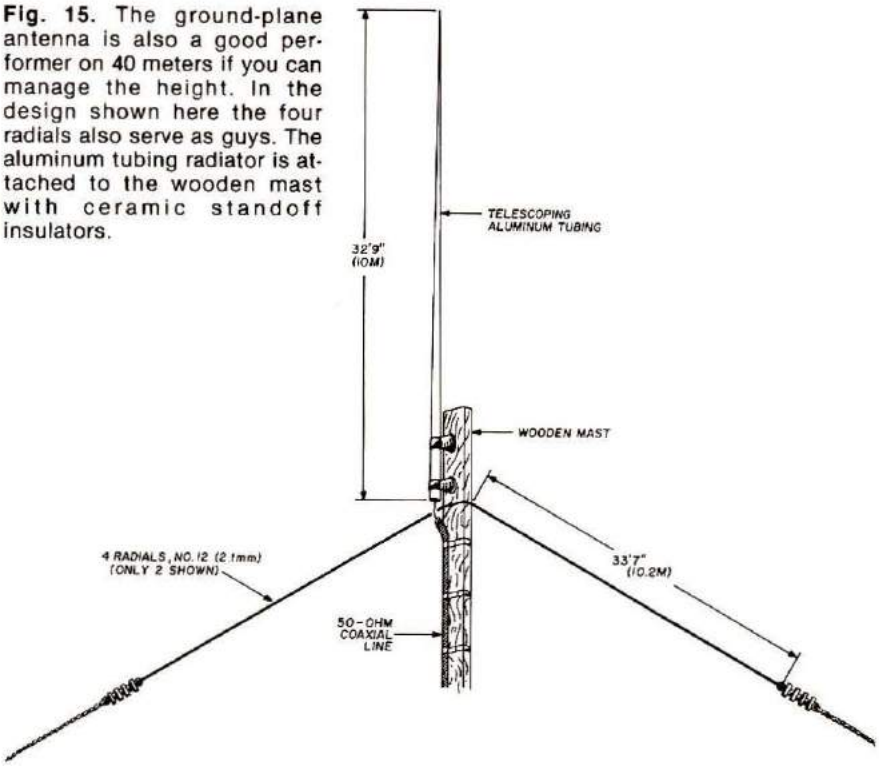



**Fig. 15.** The ground-plane antenna is also a good performer on 40 meters if you can manage the height. In the design shown here the four radials also serve as guys. The aluminum tubing radiator is attached to the wooden mast with ceramic standoff insulators.

degrees, the feedpoint impedance provides a very good match to 50-ohm coaxial cable.

Ground-plane antennas have also been used on 40 meters, but this requires a vertical radiator about 33 feet (10 meters) long, which may present construction problems. One of the best antennas I have ever used on 40 meters is the arrangement shown in **Fig. 15**. The vertical radiator was built from sections of telescoping aluminum tubing and mounted on top of a tall wooden mast; the guy wires which supported the mast also served as the radials.

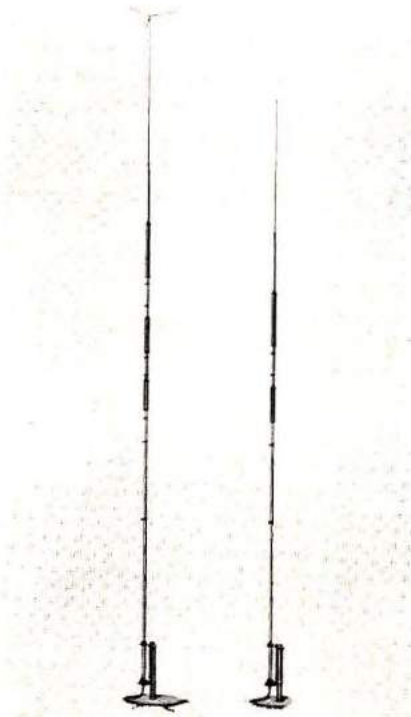
### Antenna arrays

As was mentioned earlier, the radiation pattern of any antenna is influenced by nearby objects. That's the reason why most commercial antennas are located out in open fields away from trees, buildings, and power lines which distort the shape of the pattern. You usually have little control over those things that distort the radiation pattern from your Amateur antenna, but you can put the same concept to work for you if you install more than one antenna and carefully control the way in which you feed radio energy to the system. This is called a phased array and may consist of two, three, four, or more elements. The basic two-element array is shown in **Fig. 16**.

Remember that the horizontal radiation pattern from a single vertical antenna is the same in all directions. If you add a second vertical one-half wavelength away from the first and simultaneously feed rf energy to both of them, the radiation from each of the antennas adds in such a way that the resulting pattern is bidirectional and *broadside* to the two antennas (**Fig. 16A**). Note that the transmission line to each of the verticals must be the same length for a broadside pattern.

If you change the length of the transmission lines so the radio energy from your transmitter arriving at one vertical is going through a a maximum while the rf at the other vertical is going through a minimum (180 degrees out of phase), the radiation pattern will be bidirectional in line with the two verticals (**Fig. 16B**). This is called an *end-fire* array and is much easier to do than it sounds because a transmission line which is one-half wavelength long delays the rf energy by 180 degrees. To feed the two antennas 180 degrees out of phase all you have to do is make sure that the feedline to one vertical is one-half wavelength longer than the other one.

It's also possible to switch feedlines in such a way that you can choose between the end-fire and broadside patterns from the comfort of your ham shack. The basic arrangement is shown in **Fig. 17**. The two transmission lines marked **A**



The Hy-Gain 14AVQ, left, and 12AVQ, right, are multi-band verticals for the amateur bands. The tuned traps provide automatic band switching. The 14AVQ covers 10, 15, 20, and 40 meters and is designed for use with 50-ohm coaxial cable (swr 2:1 or less on all bands); it is only 18 feet (5.5m) high and will handle a full kilo-watt. The 12AVQ is for 10, 15, and 20 meters and is only 13½ feet (4.1m) high. Kits are available to mount these antennas on your roof.

and **B** are exactly the same length. Therefore, when the switch is in the BROADSIDE position, maximum radiation will be broadside to the two verticals. When the half-wavelength section of transmission line is switched in (ENDFIRE position of the switch), the rf arriving at the vertical antenna on the right through transmission line **B** will be delayed by 180 degrees. Hence, the array will have an endfire radiation pattern. The added half-wavelength transmission line can be coiled up inside your ham shack.

You can also build a phased vertical array using two verticals spaced one-quarter wavelength apart and fed 90 degrees out of phase (one transmission line is a quarter wavelength longer than the other). The resulting pattern is called a "cardioid" and is shown in **Fig. 18**. By using a switching arrangement similar to that in **Fig. 17**, you can switch the cardioid pattern to either the right or left. Somewhat similar arrangements can be used with three, four, or more vertical elements to provide maximum radiation in desired directions (this also cuts down on interference from other directions). One commercial vertical array uses four vertical elements and is designed for use on 10 and 15 meters as well as CB. This system, shown in **Fig. 19**, uses special electronic circuits to accomplish the required phase delays to each of the vertical elements.

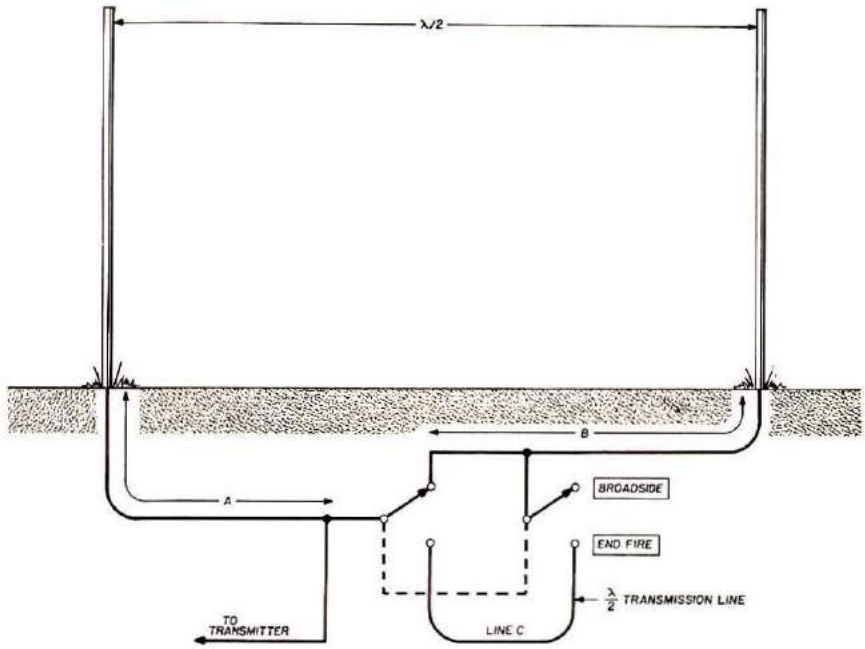



**Fig. 17.** Switching arrangement for obtaining both broadside and endfire radiation patterns with a two-element phased array. Transmission lines **A** and **B** are exactly the same length; feedline **C** is ½-wavelength long.

You can also build arrays of horizontal antennas to obtain gain and directivity. On 20, 15, and 10 meters it's usually more practical to build an array you can rotate, but on 40 meters a rotatable beam is too big for most amateurs to even consider. It can be done, but it requires a large, expensive rotator, as well as well-guyed tower. One phased horizontal array that is sometimes used on 40 meters is shown in **Fig. 20**. This antenna was first designed by W8JK back in the 1930s and is often called a flat-top beam or W8JK array. Although seldom seen today, it still provides an excellent means of obtaining both gain and directivity on 40 meters. Both the horizontal elements should be the same length; if made 60 to 80 feet (18-24 meters) long and fed with open-wire line, this array can be

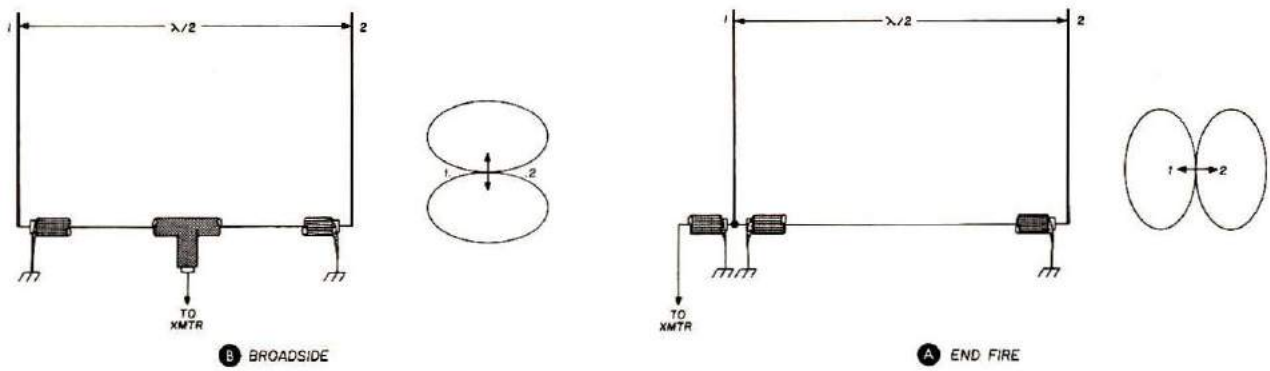



**Fig. 16.** Simple vertical array for amateur use consists of two vertical radiators spaced one-half wavelength apart. Each vertical is ¼-wavelength high and operated against a good ground system. When rf power to the two verticals is in phase (transmission lines exactly the same length), maximum radiation is broadside to the array as shown at **A**. If the rf power to one vertical is delayed by 180 degrees (transmission line to one vertical is ½-wavelength longer than the feedline to the other), maximum radiation is in line with the array or endfire, **B**.

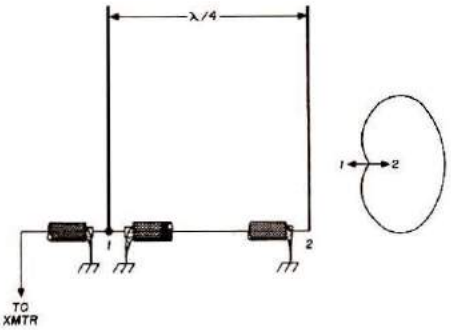


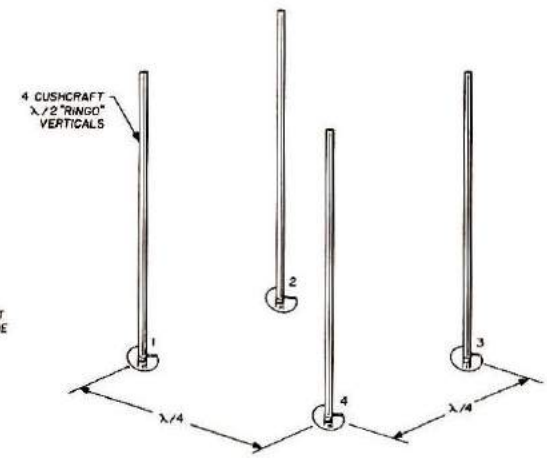

**Fig. 18.** Two quarter-wave vertical elements spaced ¼-wavelength apart and fed 90 degrees out of phase provide a cardioid radiation pattern as shown here. The 90 degree phase difference is accomplished by making the feedline to one radiator ¼-wavelength longer than the transmission line to the other vertical.

used with equally good results on both 20 and 40 meters.

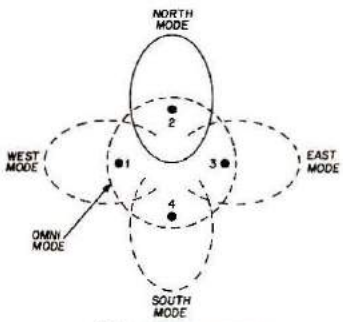
### Directional beams

One of the best ways to improve both directivity and gain, while using as little space as possible, is the multi-element array shown in **Fig. 21**. Originally designed by two Japanese engineers, Yagi and Uda, the English language description was written by Dr. Yagi, so this type of antenna is often called a Yagi beam although it is more correctly known as a Yagi-Uda array. Yagi and Uda discovered that if several half-wavelength elements were placed in close proximity to one another, they could produce gain figures comparable to those of much larger arrays.

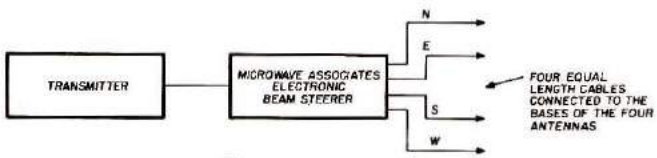
Typically, a Yagi beam has a center-fed driven element that is approximately one-half wavelength long. A slightly longer element is placed a few tenths of a wavelength away from the driven element and serves as a "reflector". Shorter elements placed in front of the driven element are called directors. It's common practice on 20 meters to use one reflector and one director, but on the higher frequency bands where element size is smaller more directors can be added for increased gain.




B ANTENNA LAYOUT



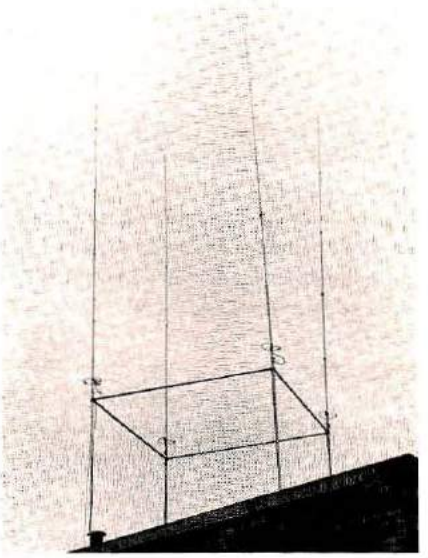

A RADIATION PATTERN




C SWITCHING SYSTEM

**Fig. 19.** Array of four vertical elements for 15 or 10 meters which uses an electronic beam switching system. The radiation pattern can be switched from the comfort of your shack for omnidirectional coverage or for maximum radiation in any one of four directions, **A**. The four half-wavelength verticals used in the system are arranged in a square, **B**. Block diagram of the system is shown in **C**.

The Microwave Associates Electronic Beam Steerer* which is used with the vertical antenna system shown in **Fig. 19**. The correct phase relationships to each of the verticals is determined by electronic circuits in the control box. The system can be used on any frequency between 18 and 36 MHz.



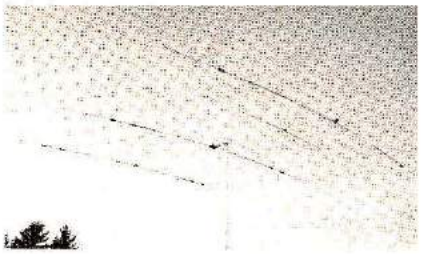
The 4-element phased vertical array shown in **Fig. 19**, set up for operation on 27 MHz. The control box for this antenna is shown in the photograph above.

**Neither the reflector nor the directors of Yagi beams have to be connected to the feedline because they receive energy in the correct phase relationship through radiation from the driven element itself. Such elements are called parasitic elements. Antennas of this type are called "beam" antennas**

*Suggested retail sales price is $100. If your local ham dealer doesn't stock the Beam Steerer, write to Microwave Associates, Inc., Burlington, Massachusetts 01803, and request the name of the distributor nearest you.

because they focus the radio energy in beams much like a searchlight, with little radiation to the rear or off to the sides. The Yagi beam is probably the most popular directive antenna in use anywhere in the world — it does require a tower and a rotator, but if you have the space and want maximum performance, someday you will probably have one in your backyard.

Another popular directional antenna that has excellent gain, is lightweight, and inexpensive to build is the cubical quad shown in **Fig. 22.** This antenna is a wire antenna



The new Cushcraft ATB-34 three-band Yagi for 10, 15, and 20 meters. This antenna functions as a three-element beam on 15 and 20 meters, and has three active elements on 10. The boom is 18 feet (5.5m) long, and the antenna weighs in at 42 pounds (19kg).

that uses some features of the Yagi except that the elements are square; two square loops, each 1 wavelength around the perimeter, are placed about 0.2 wavelength apart. Each square loop has four sides — that's the "quad" part. When you put the two loops near each other the result looks like a cube, hence its name, "cubical quad." This antenna was invented by Clarence Moore, W9LZX, in Quito, Eduador, in 1942 for radio station HCJB, the "Voice of the Andes."

Before Moore invented the cubical quad, ordinary Yagi beams were used by HCJB. However, due to the high altitude and high power of the transmitter, the Yagi elements developed very high corona discharges at their ends which caused the antennas to literally melt away after short periods of operation. Moore was chief engineer at the station at the time and conceived the quad as a solution to the discharge problem — since a loop doesn't have ends as such, there was no corona discharge. To this day, HCJB still uses a quad antenna.

Bamboo is common in the tropics, so it was used in the first quad as spreaders or "spiders" to support the wire loops. Amateurs still use bamboo if they can find it, but several firms market fiberglass poles for this purpose which are much stronger and have longer life. The feedpoint impedance of the two-element cubical quad is about 60 ohms, so it provides an excellent match to coaxial transmission lines. Although the two-element quad is the most popular, three- and four-element quads have been used to provide substantially greater gain.

Many amateurs claim they get better performance out of a quad, while others favor the Yagi. This is difficult to prove one way or the other, but the performance of a two-element quad appears to be comparable to that of a three-element Yagi. However, you don't get something for nothing — the quad has somewhat greater

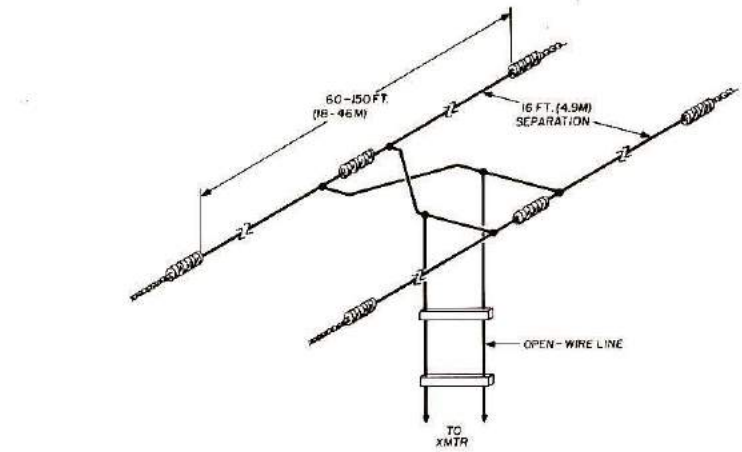



**Fig. 20.** The flat-top or W8JK horizontal array was very popular in the 1930s, but is seldom seen today. Nevertheless, this antenna is an excellent performer for DX work and can be used on more than one band. Since it uses open-wire feedline, it requires an antenna tuning unit.

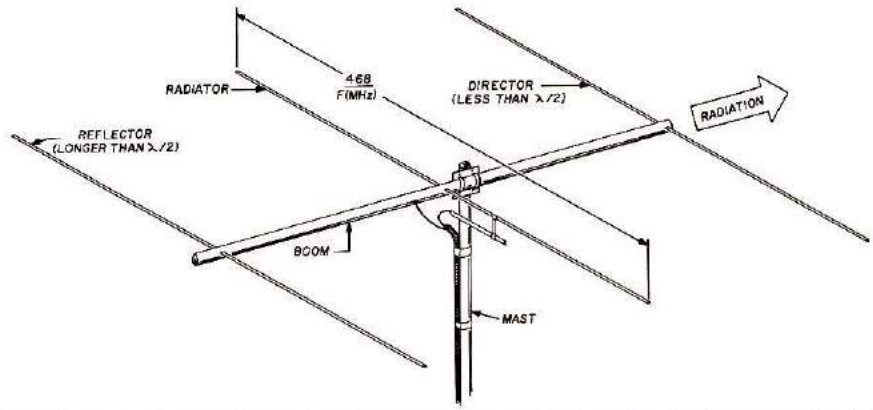



**Fig. 21.** Three-element beam or Yagi-Uda array (usually called a Yagi) is probably the most popular directional antenna used anywhere in the world. Radiation is concentrated in one direction with little radiation to the rear or off to the sides. The reflector and director do not have to be connected to the feedline — they receive energy through radiation from the driven element or radiator. On the higher frequencies where size is smaller, Yagi beams often have more than one director.

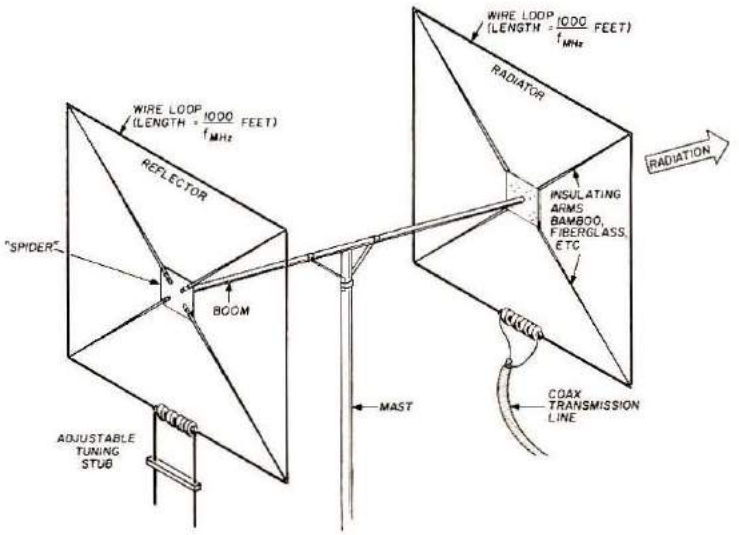



**Fig. 22.** Performance of a two-element cubical quad is similar to that of a three-element Yagi beam. The quad has somewhat higher wind resistance, but it's easy to build and uses low-cost materials.

wind resistance and may be more difficult to install on the top of your tower.

### Multiband antennas

One of the easiest ways to operate on several bands with the same antenna is to use open-wire feedline and an antenna tuner as was discussed earlier, but this is not the only way to get the job done. If you want to use coaxial feedline one of the best solutions is to use the multi-dipole arrangement shown in **Fig. 23**. In this antenna each of the individual dipoles are cut for a different Amateur band. If the ends of the antennas are separated by several feet, there is very little interaction between the antennas.

Another arrangement which is popular is the so-called "trap" antenna shown in **Fig. 24**. In this antenna the outer ends of the antenna are effectively divorced from the inner section by the tuned electronic circuits. For a dual-band 80- and 40-meter trapped dipole, for example, on the 80-meter band the traps look essentially like a short circuit so the antenna behaves as a half-wavelength dipole. On 40 meters the traps are designed to look like open circuits so only the center section of the antenna is used. This is fine in theory, but it's impossible to build traps which are 100 per cent efficient — they're not quite short circuits on 80 meters nor are they open circuits on 40. They come close, but they're not perfect. Consequently, trapped antennas have somewhat more loss (and lower efficiency) than antennas which are designed for only one band. However, if you have room for only one antenna this is an excellent way to operate on more than one band. This same basic arrangement has been used in multiband verticals and in three-band Yagi beams.

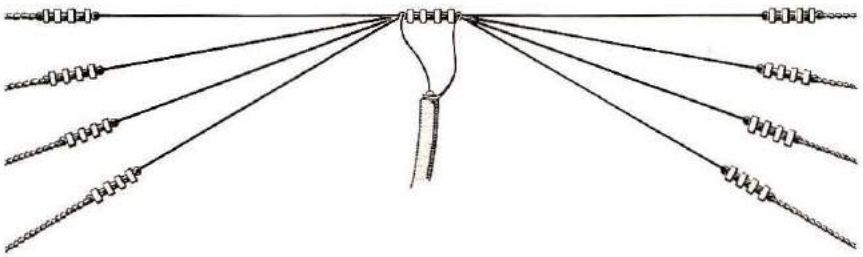


**Fig. 23.** Simple multiband antenna consists of half-wavelength dipoles stacked one beneath the other. If the ends of each of the antennas are separated by several feet, there will be little interaction.

### Summary

Although there are a number of other antenna types which have been used by amateurs, the ones discussed in this article are the most popular. If you look through any of the popular amateur antenna books, you'll find others that you might like to try. With an understanding of radiation pattern and feedpoint impedance, you can choose the antenna that best figs ohe space you have available, the bands you want to operate on, the space you have available, and how much money you want to spend. **HRH**

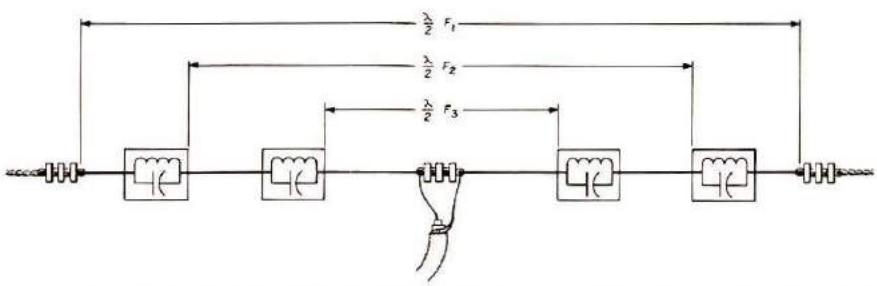



**Fig. 24.** Multiband trap dipole for operation on three different amateur bands (denoted *f1*, *f2*, and *f3*). The traps are electronic tuned circuits which effectively isolate the outer ends of the antenna on the higher frequencies. Since the traps aren't perfect, this antenna is somewhat less efficient than individual antennas for each band.